



Sinxron turbogenerator elektr parametrlari asosida texnik holatini intellektual diagnostika qilish usulini ishlab chiqish

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Dolzarbli: sinxron turbogeneratorlar elektr ta'minoti tizimida elektr energiyasini ishlab chiqaruvchi asosiy elektrotexnologik qurilmalardan biri bo'lib, ularning barqaror, ishonchli ishlashi elektr ta'minoti uzluksizligini ta'minlashda muhim ahamiyat kabs etadi. Turbogenerator ish rejimida aktiv quvvat P , reaktiv quvvat Q , chiqish klenmalaridagi kuchlanishi U , qo'zg'atish toki I_{qoz} va rotor burchak tezligi og'ishi $\Delta\omega$ kabi elektr hamda elektromexanik parametrlarning me'yoriy qiymatlaridan o'zgarishi turbogeneratorning dinamik barqarorligi, kuchlanish rejimi hamda qo'zg'atish tizimining ishlash sifatiga salbiy ta'sir ko'rsatadi. Ushbu elektr parametrlarning o'zaro bog'langan holda o'zgarishi nosozlik holatlarini faqat bitta parametr asosida baholashni murakka-blashtiradi. Shu sababli o'lgangan parametrlar bilan bir qatorda hisobiy diagnostik ko'rsatkichlardan foydalanish, ularning og'ishlarini kompleks baholash hamda turbogeneratorning joriy holatini intellektual usulda aniqlash dolzarb ilmiy-texnik muammo hisoblanadi.

Maqsad: sinxron turbogeneratorning asosiy elektr hamda elektromexanik parametrlaridagi buzulishlarni kompleks holda baholash, o'lgangan va hisobiy parametrlar orasidagi diagnostik qoldiq signallarni shakllantirish va ular asosida turbogenerator ish holatini normal, buzulish va xavfli holatlar bo'yicha aniqlash imkonini beruvchi intellektual diagnostika usulini ishlab chiqish.

Usullari: Ushbu maqolada sinxron turbogeneratorning texnik holatini elektr parametrlar asosida baholash hamda ulardagi buzulishlarni aniqlash maqsadida noaniq mantiq va sun'iy intellektga asoslangan intellektual diagnostika usuli keltirilgan.

Natijalar: tadqiqot natijalari "Navoiy issiqlik elektr stansiyasi" AJ da ishlab turgan 110 MVatt quvvatli sinxron turbogeneratorning elektr parametrlari asosida olingan va tarmoq bilan yuzaga keladigan buzulishlar asosida olingan. Taklif etilgan usulda P , Q va U parametrlarining o'zgarishi asosida I_{qoz} va ω hisobiy kattaliklari shakllantirilib, ularning real o'lgangan qiymatlar bilan solishtirilishi hisobiga qo'zg'atish tizimi va elektromexanik rejimdagi nomuvofiqliklarni qo'shimcha diagnostik belgi sifatida aniqlash imkoniyati yaratildi. Parametrlarning normallashtirilgan buzulishlari va qoldiq signallari asosida turbogenerator holatini normal, buzulish va xavfli rejimlarga ajratish algoritmi shakllantirildi. Natijada turbogeneratorning elektr parametrlaridagi buzulishlarni kompleks baholash, xavfli holatlarni erta aniqlash va keyingi adaptiv boshqaruv tizimi uchun diagnostik axborot shakllantirish imkoniyati ta'minlandi.

Kalit so'zlar: turbogenerator, tadqiqot, adaptiv, boshqaruv, kuchlanish, tok, chastota, qo'zg'atish, sinxron, rejim, iste'molchi, normal, buzulish, tizim, avariya, quvvat, parametr, diagnostika, elektr energiyasi, o'lgachov, natija.

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Разработка метода интеллектуальной диагностики технического состояния синхронного турбогенератора на основе электрических параметров

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Актуальность: синхронные турбогенераторы являются одним из основных электротехнических устройств, вырабатывающих электроэнергию в системе электроснабжения, их стабильная, надежная работа имеет важное значение для обеспечения непрерывности электроснабжения. В режиме работы турбогенератора активная мощность равна P , реактивная мощность равна Q , напряжение на выходных клеммах равно U , ток возбуждения равен I_b , а отклонение угловой скорости Ротора равно $\Delta\omega$ изменение электромеханических параметров от нормативных значений отрицательно сказывается на динамической устойчивости турбогенератора, режиме напряжения, качестве работы системы возбуждения. Взаимосвязанное изменение этих электрических параметров позволяет оценить состояние неисправности только на основе одного параметра усложняет. Поэтому наряду с измеряемыми параметрами актуальной научно-технической проблемой является использование расчетных диагностических показателей, комплексная оценка их отклонений и интеллектуальное определение текущего состояния турбогенератора.

Цель: разработка интеллектуального метода диагностики, позволяющего комплексно оценивать искажения основных электрических и электромеханических параметров синхронного турбогенератора, формировать диагностические остаточные сигналы между измеряемыми и расчетными параметрами и на их основе определять рабочее состояние турбогенератора по нормальным, искажающим и опасным состояниям.

Методы: в данной статье представлен метод интеллектуальной диагностики, основанный на неопределенной логике и искусственном интеллекте, с целью оценки технического состояния синхронного турбогенератора на основе электрических параметров и выявления в них неисправностей.

Результаты: результаты исследования были получены на основе электрических параметров синхронного турбогенератора мощностью 110 МВт, работающего на АО "Навоийская ТЭС", и на основе возникающих сбоев в работе сети. В предложенном методе $I_{вх}$ и $\omega_{в}$ рассчитывается на основе изменения параметров P , Q и $U_{в}$ качестве дополнительного диагностического признака были сформулированы расчетные величины а также возможность выявления несоответствий в системе возбуждения и электромеханическом режиме за счет их сопоставления с реальными измеренными значениями. На основе нормализованных возмущений параметров и остаточных сигналов сформирован алгоритм разделения состояния турбогенератора на нормальные, возмущенные и опасные режимы. В результате была обеспечена возможность комплексной оценки нарушений электрических параметров турбогенератора, раннего выявления опасных ситуаций и формирования диагностической информации для последующей адаптивной системы управления.

Ключевые слова: турбогенератор, исследовательский, адаптивный, контрольный, напряжение, ток, частота, возбуждение, синхронный, режим, потребитель, нормальный, поломка, система, авария, мощность, параметр, диагностика, электричество, измерение, результат.

Development of a method for intelligent diagnostics of the technical condition of a synchronous turbine generator based on electrical parameters

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Relevance: synchronous turbo generators are one of the main electro-technological devices for generating electricity in the power supply system, and their stable and reliable operation is important for ensuring the continuity of power supply. The turbogenerator operates in a mode of active power P , reactive power Q , output voltage U , excitation current I_{ex} and rotor angular velocity deviation $\Delta\omega$, as well as electrical and electromechanical parameters from their nominal values negatively affect the dynamic stability of the turbogenerator, the voltage mode, and the quality of operation of the excitation system. The variation of these electrical parameters in an interlocking way makes it possible to evaluate failure States based on only one parameter complicates. Therefore, the use of calculated diagnostic indicators along with measured parameters, their comprehensive assessment of deviations, and the intellectual determination of the current state of the turbine generator are urgent scientific and technical problems.

Aim: the development of an intellectual diagnostic method that allows you to assess the violations in the basic electrical and electromechanical parameters of a synchronous turbogenerator in a complex way, form diagnostic residual signals between measured and calculated parameters and, on their basis, determine the working condition of the turbogenerator by normal, disruptive and dangerous conditions.

Methods: this article presents an intelligent diagnostic method based on fuzzy logic and artificial intelligence to assess the technical condition of a synchronous turbo generator based on electrical parameters and to detect faults in them.

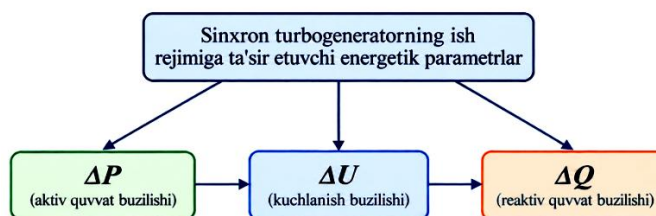
Results: the research results were obtained based on the electrical parameters of a 110 MW synchronous turbine generator operating at the JSC "Navoi Thermal Power Plant" and based on the disturbances occurring in the network. In the proposed method, I_{ex} based on changes in the parameters P , Q , and U_{ac} and w_h accounting magnitudes were formed, and due to their comparison with real measured values, it was possible to identify inconsistencies in the excitation system and electromechanical mode as an additional diagnostic sign. An algorithm for classifying the state of a turbogenerator into normal, abnormal and dangerous modes based on normalized parameter disturbances and residual signals was developed. As a result, it was possible to comprehensively assess the disturbances in the electrical parameters of the turbine generator, early detect dangerous conditions, and form diagnostic information for the subsequent adaptive control system.

Keywords: turbogenerator, research, adaptive, control, voltage, current, frequency, excitation, synchronous, mode, consumer, normal, breakdown, system, accident, power, parameter, diagnostics, electricity, measurement, result.

1. Kirish (Introduction)

Hozirgi kunda elektr ta'minoti tizimida sinxron turbogeneratorlarning o'rini beqiyosdir. Ularning ishonchli va barqaror ishlashi bugungi kunning dolzarb masalardan biri hisoblanadi. Bugungi kunda elektr energiyasini ishlab chiqarish jarayonining uzluksizligini ta'minlovchi eng muhim elektrotexnologik qurilmalardan bir bu sinxron turbogeneratordir. Sinxron turbogenerator elektr tarmog'i bilan parallel ishlash jarayonida turli statik hamda dinamik buzilishlar ta'sirida bo'ladi. Bunday buzilishlar natijasida turbogeneratorning stator chiqish klinmalaridagi kuchlanishi, aktiv va reaktiv quvvati, rotor aylanish tezligi, yuklanish burchagi va qo'zg'atish toki nominal qiymatidan og'ishiga olib keladi. Shu sababli turbogenerator ish rejimini tavsiflovchi asosiy elektr va elektromexanik parametrlarni uzluksiz nazorat qilish hamda ularning o'zgarishini o'z vaqtida aniqlash muhim ilmiy-amaliy masala hisoblanadi [1,2].

Tashqi elektr ta'minoti tizimidagi buzilishlar turbogenerator parametrlariga o'zaro bog'liq holda ta'sir qiladi. Jumladan, aktiv quvvatning ΔP o'zgarishi turbina mexanik quvvati bilan generator elektr quvvati o'rtasidagi muvozanatning buzilishiga va elektromexanik tebranishlarning yuzaga kelishiga sabab bo'ladi [3]. Kuchlanishning ΔU o'zgarishi esa reaktiv quvvat almashinuvi va qo'zg'atish tizimi ish rejimiga ta'sir qiladi. Shu sababli, reaktiv quvvatning ΔQ o'zgarishi stator klenmalaridagi kuchlanish, qo'zg'atish toki va quvvat koeffitsiyentining o'zgarishiga olib keladi. Sinxron turbogenerator tashqi elektr ta'minoti bilan parallel ishlaganda tarmoqda yuzaga keladigan buzilishlarni sinxron turbogeneratorga ta'sir etuvchi omillar quyidagi 1-rasmda keltirilgan [4,5].



1-rasm. Tashqi elektr ta'minotida yuzaga keladigan buzilishlarning sinxron turbogeneratorning elektr parametrlariga ta'sirining funksional sxemasi

Fig. 1. Functional diagram of the effect of disturbances in the external power supply on the electrical parameters of a synchronous turbine generator

Yuqorida 1-rasmda tashqi elektr ta'minotidagi buzilishlarning sinxron turbogeneratorga ta'sir etuvchi asosiy omillari hamda ular orasidagi o'zaro bog'liqlik keltirilgan. Bunda aktiv quvvat buzilishi ΔP , kuchlanish buzilishi ΔU va reaktiv quvvat buzilishi ΔQ mustaqil jarayonlar sifatida emas, balki bir-biri bilan bog'liq holda diagnostik parametrlar sifatida qaraladi. Bir parametrlarning me'yoriy qiymatdan og'ishi boshqa parametrlarning ham o'zgarishiga sabab bo'lishi mumkin, bu esa turbogenerator holatini kompleks baholash zaruratini yuzaga keltiradi [6].

Shu sababli sinxron turbogeneratorning P , Q , U , I_{qor} va $\Delta\omega$ parametrlarini birgalikda tahlil qilish, ularning me'yoriy holatdan og'ishini aniqlash va hosil bo'lgan buzilishlarni **normal, buzulish va xavfli** holatlarga ajratish imkonini beruvchi intellektual diagnostika usulini ishlab chiqish dolzarb masala hisoblanadi. Bunday yondashuv turbogeneratorning joriy ish holatini tezkor baholash va keyingi adaptiv boshqaruv uchun zarur diagnostik axborotni shakllantirish imkonini beradi [7].

2. Materiallar va usullar (Methods and materials)

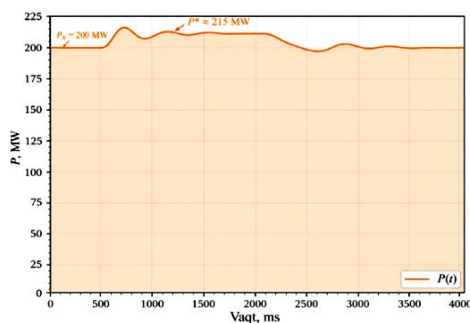
Tarmoqdagi aktiv quvvatning o'zgarishi. Aktiv quvvatning o'zgarishi ($\Delta P(t)$) turbogeneratorning elektr quvvati bilan turbina mexanik quvvati o'rtasidagi muvozanatni buzib, rotor tezligi va yuklanish burchagida tebranishlarni yuzaga keltiradi.

Sinxron turbogeneratorning aktiv quvvatining boshlang'ich qiymatdan og'ishi quyidagicha ifodaladi:

$$\Delta P(t) = P_e(t) - P_{e0}; \quad (1)$$

bu yerda, $P_e(t)$ – turbogeneratorning t vaqtidagi joriy aktiv quvvati, [MVt];

P_{e0} – buzilish yoki yuklama o'zgarishidan oldingi boshlang'ich barqaror aktiv quvvat, [MVt].



2-rasm. Sinxron turbogeneratorning aktiv quvvat buzulish og'ishlari ko'rinishi
Fig. 2. Appearance of active power disturbances of a synchronous turbogenerator

Yuqorida 2-rasmda TTB-200-2MV3 turbogeneratorining tashqi yuklama o'zgarishiga nisbatan aktiv quvvat bo'yicha o'tkinchi jarayoni holati keltirilgan. Elektr ta'minoti tizimiga quyilgan yuklama 15 MVt ga oshirilganda turbogeneratorning nominal quvvati $P_{e0} = 180$ MVt boshlang'ich qiymatdan yangi barqaror qiymatga o'tadi. Ushbu o'tkinchi jarayonda aktiv quvvat og'ishi musbat bo'lib, $\Delta P(t) \approx 15$ MVtni tashkil etadi. O'tkinchi jarayon ish rejimi vaqtida yuzaga kelgan tebranishlarning asta-sekin kamayishi tizimda elektromexanik tebranishlarning so'ndirilayotganini ko'rsatadi. Yuklama boshlang'ich holatiga qaytarilganda aktiv quvvat og'ishi nolga intilib, turbogeneratorning barqaror ish rejimi tiklanadi [8].

Tarmoqdagi kuchlanishning buzulishining sinxron turbogeneratorga ta'siri. Sinxron turbogeneratorning stator chulg'am chiqish klenmasidagi kuchlanishning o'zgarishi ($\Delta U(t)$) asosiy muammolar biridir. Unda elektr ta'minoti tizimidagi yuklama yoki elektr parametrlari o'zgartirilganda turbogenerator stator chiqish klenmalaridagi kuchlanishning qiymati pasayishi yoki oshishi mumkin. Bu holat reaktiv quvvat almashinuvining buzilishi, qo'zg'atish tizimining ortiqcha yuklanishi va turbogenerator ishlash barqarorligining pasayishiga olib keladi. Elektr ta'minoti tizimida yuzaga keladigan kuchlanishning buzilishi quyidagicha ifodalanadi:

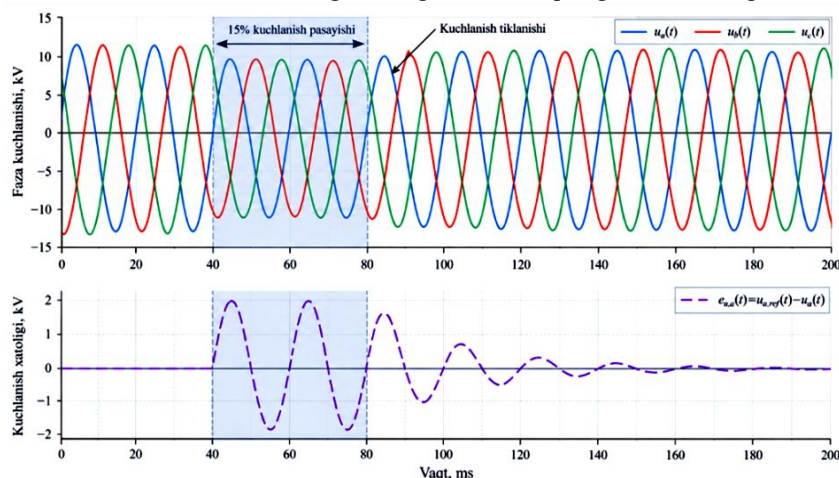
$$\Delta U(t) = U_{nom}(t) - U_t(t); \quad (2)$$

bu yerda; $U_{nom}(t)$ – turbogenerator stator chiqish klenmalarida kuchlanishning berilgan qiymati, ya'ni rostlagich ushlab turishi kerak bo'lgan qiymati yoki turbogenerator pasportidagi nominal kuchlanish hisoblanadi. Tadqiqot obektidagi turbogeneratorning nominal kuchlanishi: $U_{nom}(t) = 15,75$ kV.

$U_t(t)$ – turbogenerator stator chulg'amining chiqish klemmalarida real vaqtda o'lchanayotgan haqiqiy kuchlanishdir. Uni d va q o'qlar bo'yicha modeli quyidagicha:

$$U_t(t) = \sqrt{u_d^2(t) + u_q^2(t)}. \quad (2)$$

(1) tenglama sinxron turbogenerator statorining chiqish klemmalaridagi tarmoq kuchlanish moduli aniqlaydi. Bunda $U_d(t)$ va $U_q(t)$ – Park almashtirishi orqali olingan, o'zaro perpendikulyar d va q o'qlari bo'yicha kuchlanish tashkil etuvchilaridir. Ularning geometrik yig'indisi asosida hisoblangan $U_t(t)$ qiymati avtomatik kuchlanish rostlagichining teskari aloqa signali sifatida qo'llanadi [9,10].



3-rasm. Sinxron turbogeneratorning stator chiqish klenmalaridagi kuchlanishning o'zgarishining ko'rinishi, **a)** faza kuchlanishining o'zgarish grafigi, **b)** qisqa vaqt oralig'ida kuchlanishning buzulishi.
Fig. 3. The appearance of voltage changes in the stator output terminals of a synchronous turbo generator is, **a)** a graph of phase voltage changes, **b)** voltage distortion over a short period of time.

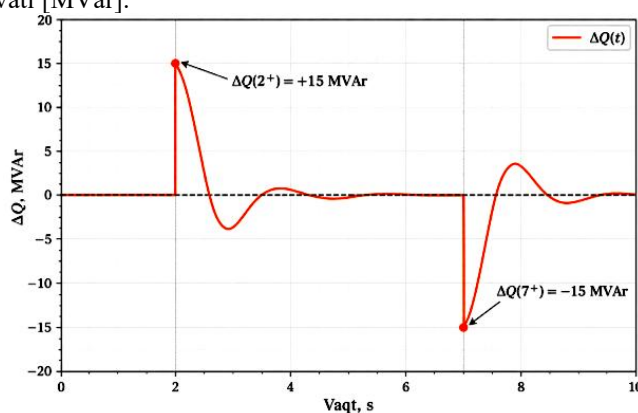
Yuqorida keltirilgan 3-rasmda tadqiqot obektidagi TGV-200-2MU3 rusumidagi turbogeneratorning stator chiqish klenmalaridagi kuchlanishining vaqt bo'yicha o'zgarishi hamda kuchlanish pasayishidan keyingi tiklanish jarayoni ko'rsatilgan. 40-80 ms oralig'ida stator chiqish klenmalaridagi kuchlanishining 15 % ga kamayishi kuzatiladi. Ushbu buzilish natijasida faza kuchlanishlari amplitudasi vaqtincha pasayadi, buzilish bartaraf etilgandan so'ng esa tizimning o'tkinchi jarayoni boshlanadi.

Pastki grafikda kuchlanish xatoligi $U_t(t)$ ning vaqt bo'yicha o'zgarishi tasvirlangan. Kuchlanish pasayishi va undan keyingi tiklanish davrida xatolik signalida so'nuvchi tebranishlar yuzaga keladi. Vaqt o'tishi bilan ushbu tebranishlarning amplitudasi kamayib, xatolik qiymati nolga yaqinlashadi. Bu holat turbogeneratorning kuchlanish bo'yicha turg'un ish rejimiga qaytishini ifodalaydi. Mazkur rasmdagi grafiklar kuchlanish buzilishlarini diagnostika qilishda ΔU parametrining dinamik buzilishlarini, o'tkinchi jarayon davomiyligini hamda tizimning tiklanish xususiyatlarini baholash imkonini beradi [11].

Reaktiv quvvatning o'zgarishining turbogeneratorga ta'siri. Reaktiv quvvatning o'zgarishi (ΔQ) esa terminal kuchlanishi, qo'zg'atish toki va quvvat koeffitsiyentiga bevosita ta'sir qilib, turbogeneratorning ortiqcha yoki yetarli bo'lmagan qo'zg'atish rejimiga o'tishiga sabab bo'lishi mumkin.

$$\Delta Q(t) = Q_{nom}(t) - Q_{e0}(t); \quad (3)$$

bu yerda, $Q_{nom}(t)$ – reaktiv quvvatning belgilangan qiymati, [MVar]; $Q_{e0}(t)$ – turbogeneratorga tarmoqdagi reaktiv quvvati [MVar].



4-rasm. Tarmoqdagi reaktiv quvvatni o'zgarishi.

Fig. 4. Change in reactive power in the network.

Yuqoridagi 4-rasmda TGB-200-2MV3 turbogeneratorining reaktiv quvvat bo'yicha o'tkinchi jarayoni keltirilgan. $t = 3$ sda $Q_{nom}(t)$ qiymati 100 MVar dan 115 MVar gacha oshirilganda $\Delta Q(t) = +15 \text{ MVar}$ boshqaruv buzilishi hosil bo'lib, qo'zg'atish tokini oshirish zarurati yuzaga keladi. $t = 7$ sda topshiriq boshlang'ich qiymatga qaytarilganda esa $\Delta Q(t) = -15 \text{ MVar}$ bo'lib, qo'zg'atish toki kamaytiriladi. $Q_{e0}(t)$ ning so'nuvchi tebranishlar bilan $Q_{nom}(t)$ ga yaqinlashishi va $\Delta Q(t)$ ning nolga intilishi tanlangan boshqaruv modelida reaktiv quvvat buzilishi bilan bartaraf etilayotganini ko'rsatadi [12].

3. Natijalar (Results)

Ishlab chiqilgan maskur intellektual diagnostika usuli sinxron turbogeneratorning ish rejimida uchraydigan kuchlanish og'ishi, aktiv quvvatning beqarorlashuvi va qo'zg'atish zanjiridagi o'zgarishlarni aniqlovchi yagona adaptiv diagnostika usuli hisoblanadi. Mazkur usulda o'lgan signallarning joriy qiymatlarini berilgan qiymatlar bilan solishtirib, ularning og'ish chegaralarini intellektual ravishda qayta ishlaydi hamda tizim holatini tavsiflovchi xulosa hosil qiladi. Natijada, maskur usul sinxron turbogeneratorning normal, o'tkinchi va buzilishli holatlari orasidagi farqlarni aniqlash imkonini beradi (5-rasm).

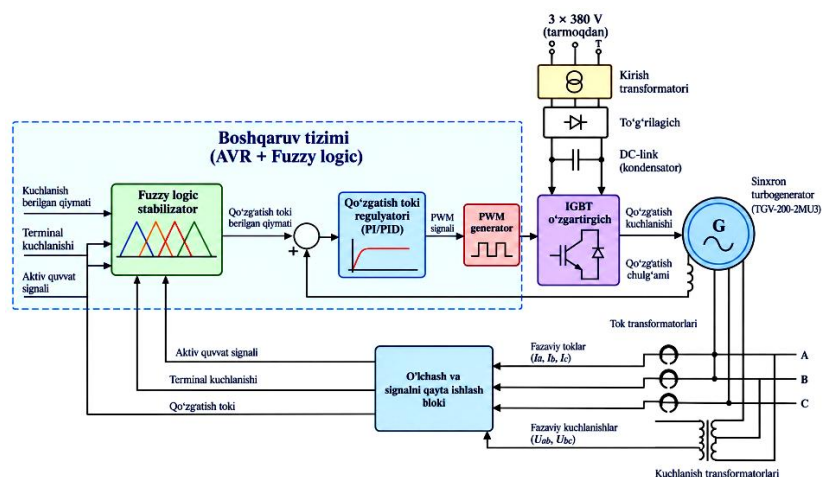
5-rasmda sinxron turbogeneratorning elektr parametrlarini kuzatish, qayta ishlash va diagnostika qilishga mo'ljallangan diagnostika va boshqaruv sxemasi keltirilgan. Tizimning kirish qismida turbogenerator stator chiqish klenmalaridagi kuchlanishi U_t , aktiv quvvat signali P_t va qo'zg'atish toki $I_{qo'z}$ qiymalarining ma'lumotlari qabul qilinadi. Ushbu signallar noaniq mantiqqa asoslangan stabilizator blokida qayta ishlanib, turbogeneratorning joriy holatini baholashga xizmat qiluvchi diagnostik mezonlar shakllantiriladi (1-jadval).

Keyingi bosqichda hosil qilingan axborot qo'zg'atish toki regulyatori bilan bog'langan holda PWM generatori va IGBT o'zgartirgich orqali ijro qismiga uzatiladi. O'lchash va signalni qayta ishlash bloki fazaviy toklar (I_a, I_b, I_c) hamda fazalararo kuchlanishlar (U_{ab}, U_{bc})ni qayta ishlab, tizimga

teskari aloqa ko'rinishida uzatadi. Shu asosda turbogeneratorning ishlash rejimi haqida ishonchli diagnostik xulosa qabul qilinadi [13,14].

Taklif etilgan diagnostika tizimida stator chiqish klenmalaridagi kuchlanishi, aktiv quvvat va qo'zg'atish toki og'ishlari lingvistik o'zgaruvchilar sifatida baholanadi. Har bir kirish parametriga "Past", "Normal" va "Yuqori" holatlar birlashtirilgan, ularning kombinatsiyasi asosida turbogeneratorning normal, individual buzilishli yoki kompleks buzilishli ish holati aniqlanadi. Yuqoridagi 1-jadvalga asosan qarorlar jadvali noaniq-mantiqiy diagnostika blokining bilimlar bazasini shakllantiradi.

Yuqoridagi 5-rasmdagi sxemada U_t , P_e va $I_{qo'z}$ signallari qayta ishlanadi. Noaniq mantiq bloki ularni baholab, $I_{qo'z}^*$ - qo'zg'atish tokining berilgan qiymatini shakllantiradi. Keyin PI/PID regulyator va PWM generator orqali IGBT o'zgartirgich boshqariladi. Natijada quyidagi asosiy kattaliklar olinadi:



5-rasm. Sinxron turbogeneratorning elektr parametrlaridagi buzilishlarni intellektual diagnostika qilish tizimining prinsipial sxemasi

Fig. 5. Block diagram of an intelligent system for diagnosing disturbances in the electrical parameters of a synchronous turbine generator

1-jadval. Fuzzy logic noaniq-mantiq tizimni Mamdani qoidalariga asoslangan diagnostika qarorlar jadvali

Table 1. Fuzzy logic fuzzy logic system Mamdani rule-based diagnostic decision table

Qoida	Mamdani diagnostika qoidasi
R_1	$\text{AGAR} \begin{cases} \Delta U = N \\ \Delta P = N \\ \Delta I_{qo'z} = N \end{cases} \quad \text{BO'LSA, holat = Normal}$
R_2	$\text{AGAR} \begin{cases} \Delta U = Past \\ \Delta P = N \\ \Delta I_{qo'z} = N \end{cases} \quad \text{BO'LSA, holat = Kuchlanish buzilishi}$
R_4	$\text{AGAR} \begin{cases} \Delta U = N \\ \Delta P = Past \\ \Delta I_f = N \end{cases} \quad \text{BO'LSA, holat = Aktiv quvvat buzilishi}$
R_6	$\text{AGAR} \begin{cases} \Delta U = N \\ \Delta P = N \\ \Delta I_{qo'z} = Past \end{cases} \quad \text{BO'LSA, holat = Qo'zg'atish toki buzilishi}$
R_8	$\text{AGAR} \begin{cases} \Delta U = Past \\ \Delta P = Past \\ \Delta I_f = Past \end{cases} \quad \text{BO'LSA, holat = Kompleks buzilish, Avariya holatga yaqin}$

Stator chiqish klenmalaridagi kuchlanishini holatini tiklanish:

$$U_t(t) \rightarrow U_{tar}; \quad (4)$$

ya'ni kuchlanish pasayishi yoki oshishidan keyin turbogenerator kuchlanishi berilgan qiymatga yaqinlashadi.

Qo'zg'atish tokining o'zgarishi :

$$I_{qo'z}(t) \rightarrow I_{qo'z}^*; \quad (5)$$

bu grafik IGBT tizimi qo'zg'atish tokini qanchalik tez va silliq rostlayotganini ko'rsatadi.

Qo'zg'atish kuchlanishi :

$$U_{qo'zd} = m_{qo'z} U_{o'zgarimas}; \quad (6)$$

bu IGBT o'zgartirgichning chiqish kuchlanishi bo'lib, rotor qo'zg'atish chulg'amiga beriladi.

Fazaviy toklar :

$$I_a(t), I_b(t), I_c(t); \quad (7)$$

ular orqali toklar simmetriyasi, o'tkinchi jarayon va buzilish holati aniqlanadi.

Fazalararo kuchlanishlar :

$$U_{ab}(t), U_{bc}(t); \quad (8)$$

ular stator chiqish klenmalarining kuchlanishining buzilishi yoki tiklanishini ko'rsatadi.

Ushbu sxema orqali elektr parametrlaridagi buzilish aniqlanadi va uning turbogeneratorga ta'siri vaqt bo'yicha kuzatiladi. Mislo tariqasida, kuchlanish pasaysa, U_t kamayadi, fuzzy blok bu og'ishni baholaydi, $I_{qo'z}^*$ oshiriladi, PWM orqali $m_{qo'z}$ o'zgaradi va IGBT chiqishidagi $U_{qo'z}$ ortadi. Natijada qo'zg'atish toki ko'payib, generator terminal kuchlanishi yana nominal qiymatga yaqinlashadi [15].

Natijada quyidagi elektr parametrlarni grafiklarni 3D ko'rinishida Matlab dasturi yordamidan amalga oshiriladi:

$$U_t(t), I_{qo'z}(t), P_t(t), U_{qo'z}(t); \quad (9)$$

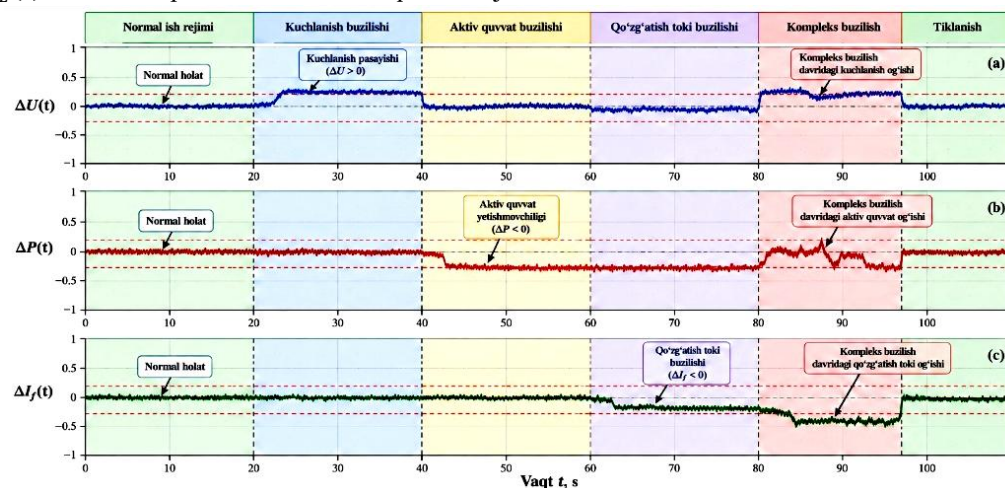
va diagnostika uchun (6-rasm):

$$\Delta U(t), \Delta P(t), \Delta I_{qo'z}(t) \quad (10)$$

Normal holatda barcha parametrlar ruxsat etilgan chegarada bo'ladi; buzilish holatida bir yoki bir nechta parametr me'yoriy qiymatdan chetga chiqadi; xavfli holatda esa parametrlarning katta yoki bir vaqtdagi kompleks og'ishi kuzatiladi:

$$H(t) = \{\text{normal, buzulish, xavfli holat}\}.$$

Bu yerda $H(t)$ - diagnostika tizimining t vaqtidagi yakuniy qarori. Ushbu qaror $\Delta U(t)$, $\Delta P(t)$ va $\Delta I_{qo'z}(t)$ kabi kirish parametrlarini tahlil qilish natijasida shakllanadi.



6-rasm. Sinxron turbogeneratorning elektr parametrlari vaqt bo'yicha o'zgarishi

Fig. 6. Time variation of electrical parameters of a synchronous turbogenerator

Yuroqidagi 6-rasmida sinxron turbogeneratorning diagnostika jarayonida foydalaniladigan asosiy kirish signallari - $\Delta U(t)$, $\Delta P(t)$ va $\Delta I_{qo'z}(t)$ ning vaqt bo'yicha o'zgarishi keltirilgan. Grafiklardan normal ish rejimi, alohida parametr buzilishlari hamda kompleks buzilish holatlarida signal amplitudalarining o'zgarish xarakteri kuzatiladi. Belgilangan chegaraviy qiymatlar diagnostik qaror qabul qilish uchun mezon sifatida xizmat qiladi. Parametrlarning ruxsat etilgan chegaradan chiqishi mos ravishda kuchlanish, aktiv quvvat yoki qo'zg'atish toki bo'yicha buzilish mavjudligini ko'rsatadi, bir nechta signalning bir vaqtda sezilarli og'ishi esa kompleks buzilish holatini ifodalaydi. Shu bilan birga, mazkur grafiklar turbogenerator holatini vaqt bo'yicha baholash va Mamdani qoidalari asosida diagnostik xulosa shakllantirish uchun ma'lumotlar bazasini yaratadi.

4. Xulosa (Conclusion)

Xulosa qilib shuni aytish mumkinki, ushbu maqolada sinxron turbogeneratorning elektr parametrlaridagi buzilishlarni kompleks baholash va ularni intellektual usulda diagnostika qilish usuli ishlab chiqildi. Taklif etilgan usulda turbogeneratorning stator chiqish klenmalaridagi kuchlanishi, aktiv quvvati va qo'zg'atish toki kabi asosiy parametrlarning me'yoriy qiymatlardan og'ishlari diagnostik kirish signallari sifatida qabul qilinib, ularning o'zaro bog'liq holda o'zgarishi tahlil qilindi. Parametrlarni yagona baholash mezoniga keltirish uchun normallashtirish amalga oshirildi hamda ularning holati "Past", "Normal" va "Yuqori" lingvistik darajalarda ifodalandi. Diagnostik qarorni shakllantirishda Mamdani noaniq-mantiqiy xulosa chiqarish mexanizmi, ekspert qoidalar bazasi, minimum-maksimum inferensiya va og'irlik markazi asosidagi defuzzifikatsiya usulidan foyda-

lanildi. Natijada turbogeneratorning ish holatini normal, alohida parametr buzilishi va bir nechta parametrlarning bir vaqtda og'ishi bilan tavsiflanadigan kompleks xavfli holatlarga ajratish imkoniyati yaratildi. Olib borilgan tadqiqot davomida aktiv quvvat, kuchlanish va qo'zg'atish toki o'zgarishlarining vaqt bo'yicha dinamik xususiyatlari baholanib, $\Delta U(t)$, $\Delta P(t)$ va $\Delta I_{qoz}(t)$ signal-larining diagnostik axborot manbai sifatida foydalanish mumkinligi asoslandi. Taklif etilgan maskur usul elektr parametrlaridagi individual va kompleks buzilishlarni erta aniqlash, ularning rivojlanish darajasini baholash hamda turbogeneratorning joriy holati bo'yicha yakuniy diagnostik xulosa shakllantirish imkonini beradi. Shu bilan birga, hosil qilingan diagnostik axborot keyingi bosqichda turbogenerator qo'zg'atish tizimining adaptiv boshqaruv algoritmini shakllantirish uchun asos bo'lib xizmat qiladi.

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